The effects of steel fiber waste tyre on properties of high strength fly ash concrete

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Abstract. The utilization of steel fiber from waste tyres can be an alternative to reduce waste tyres due to the increase of tyre production in Indonesia annually. Steel fiber from waste tyre can be added to concrete mix to improve the concrete properties. In this study, the effects of steel fiber waste tyre (SFWT) on high strength concrete containing fly ash was investigated experimentally. The content of fly ash in the high strength concrete is 30% of being partially replaced the cement weight. Steel fiber waste tyres are obtained from extracting the steel wire of the waste tyres and then cut into 4 cm long. The addition of SFWT on the high strength fly ash concrete is 0.5%, 1.0%, 1.5%, and 2% by concrete volume. The mechanical properties of concrete such as compressive strength, tensile strength, and flexural strength are tested at day 28. The test results show that the addition of 2 % SFWT on high strength fly ash concrete increase the compressive strength, tensile strength, and flexural strength of the concrete by around 9.99 %, 63.75 %, 18.18 %, respectively.

1 Introduction

Concrete is the most widely used construction material in the world because of its ability to be formed easily in various formations and shapes. Unreinforced concrete is a brittle material, with low tensile strength, limited ductility, little resistance to cracking, incapable of accommodating large deformations, and low impact strength [1-2]. Concrete deficiencies to the tensile strength can be overcome by the addition of fiber in the mix [3].

Utilization of steel fiber from used tires can be an alternative in dealing with environmental problems caused by waste tires that are increasing due to increased tire production every year, especially in Indonesia. As informed by the Entrepreneur Association of the tire in Indonesia (APBI) stated that the sale of tires for four wheels in 2017 is expected to rise to 77-78 million tires. The projection of car tire sales is up 8% compared to the actual sales of tires in 2016.

The strength of high strength concrete is also influenced by the porosity caused by the relatively large concrete forming material. Also, the water-cement factor also affects porosity, but with the use of high strength concrete that has a relatively small water-cement factor and porosity in the concrete can be reduced. Reducing porosity caused by the use of a relatively large aggregate can be done by adding pozzolanic ingredients with right grain

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size so that the subtle material is capable of filling the existing cavities in the concrete to the maximum [4]. One example of the pozzolanic material is fly ash. The utilization of fly ash as a substitute material of cement in high strength concrete shows that the higher the fly ash content is used, the higher the compressive strength, but the compressive strength will decrease if there is too much fly ash be used as partial replacement of cement [5].

In this study, the effect of the steel fiber waste tire (SFWT) on high strength concrete containing fly ash was investigated experimentally. High strength concrete containing fly ash hereafter refers to high strength fly ash (HSFA) concrete.

2 Materials and methods

2.1 Material used

2.1.1 Cement

The cement used in this study is Ordinary Portland Cement (OPC) produced by Padang Cement Factory, West Sumatera-Indonesia.

2.1.2 Fine aggregate

The local fine aggregate with a maximum size of 4.75 mm was used in this study. Specific gravity and fineness modulus of the fine aggregate are 2.56 and 1.9, respectively.

2.1.3 Coarse aggregate

The coarse aggregate has a size of 5-10 mm with specific gravity of 2.75.

Fig. 1. Waste tyre.

Fig. 2. Steel fibers extracted from waste tyre.

Fig. 3. The 4 cm length of steel fiber waste tyre.

Fig. 4. Fly ash material.

2.1.4 Water

Fresh potable water without any impurities was used for mixing and curing concrete.

2.1.5 Steel fiber waste tyre

In this study, the steel fibers extracted from waste tires (Fig. 1) were added in the concrete mix. Steel fibers from waste tires were obtained from extracting steel wire from the waste tires, and then, they were cut along 4 cm (Fig. 2-3). Those steel fibers were added in concrete mixes with different contents: 0%, 0.5%, 1.0%, 1.5%, and 2% by the concrete volume. Table 1 shows the properties of the steel fiber waste tire (SFWT).

Table 1. Properties of steel fiber waste tyre (SFWT).

Shape	Irregular, Sharp
Surface Texture	Invisible
Size	5 mm diameter and 40 mm length
Aspect Ratio	80
Density	7850 Kg/m^3
Tensile strength	500-2000 N/mm^2

2.1.6 Fly ash

Fly ash is the residue of the coal burning process of the steam power plant and used as the cement replacement in the concrete mix (Fig. 4). The chemical composition of fly ash is presented in Table 2.

Table 2. Chemical composition of fly ash.

Chemical composition	**Content (%)**
H_2O (from the original example) percent of dry samples (105-110^{O}C)	0.16
Silicon Dioksida SiO_2	51.76
Iron (III) Oxide, Fe_2O_3	9.96
Aluminum Oxide, Al_2O_3	26.47
Potassium Oxide, CaO	10.23
Magnesium Oxide, MgO	0.86
Sulfur Trioxide, SO_3	0.32
Lost in annealing	0.22
Alkali as NA_2O	0.19
SiO_2+Al_2O_3+Fe_2O_3	88.19

2.1.7 Superplasticizer

Superplasticizer used in this study was Sikament-NN by Sika. This chemical admixture meets the technical requirements by ASTM C-494 Type A & F and EN 934-2: 2001.

3 Experimental program

3.1 Mix proportions of concrete

The concrete mix is designed according to the American Concrete Institute (ACI) method 211.4R-93. The ratio of water-cement to this high strength concrete mix is 0.325 to obtain a targeted compressive strength of 60 MPa. Five high strength fly ash (HSFA) concrete mixture proportions were made in this study. The content of fly ash in each mix is 30% by partially replaced the weight of cement. The steel fiber waste tyre was added to the HSFA concrete with percentage of 0%, 0.5%, 1.0%, 1.5%, and 2.0% by the concrete volume. The mix proportion of the HSFA with different SFWT contents is given in Table 3.

Table 3. Mix proportions of HSFA concrete with different SFWT contents.

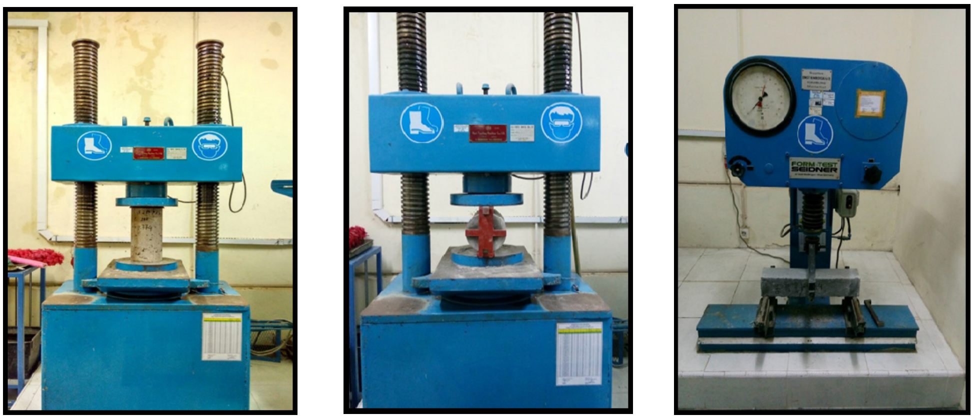
Material (kg/m^3)	**SF0**	**SF0.5**	**SF1.0**	**SF1.5**	**SF2.0**
Cement (kg/m^3)	393.0	393.0	393.0	393.0	393.0
Fine Agg. (kg/m^3)	638.7	638.7	638.7	638.7	638.7
Coarse Agg. (kg/m^3)	902.6	902.6	902.6	902.6	902.6
Water (kg/m^3)	214.8	214.8	214.8	214.8	214.8
SFWT (%)	0.0	0.5	1.0	1.5	2.0
Fly Ash (kg/m^3)	168.4	168.4	168.4	168.4	168.4
Sikament-NN (%)	2.00	2.00	2.00	2.00	2.00

3.2 Casting of specimens

There are 35 specimens were cast in this study. These specimens consist of 20 cylinder specimens for compressive and splitting tensile strength test, and ten beam test specimens for the flexural strength test. The cylinders specimens were cast using cylindrical molds with a diameter of 15 cm and a height of 30 cm, while the beam specimens were cast with the size of 10x10x50cm. All samples were cured along 28 days.

3.3 Testing of specimens

Testing of compressive strength and splitting tensile strength are conducted in cylindrical specimens using the testing machine at the Concrete Laboratory of Semen Padang Factory (Fig. 5a-5b) based on SNI 03-1972-2011 and SNI 2491: 2014, respectively. Flexural testing is conducted in beam specimens using the flexural testing machine at the Concrete Laboratory of Semen Padang Factory (Fig. 5c) based on SNI 4154: 2014.



(a) (b) (c)

Fig. 5. Test of concrete mechanical properties (a) compressive strength, (b) splitting tensile strength, (c) flexural strength.

4 Results and discussion

4.1 Compressive strength

Table 4 and Fig. 6 show the test results for the compressive strength of the specimens at day 28. It can be seen that the compressive strength of HSFA concrete increases as well as the increase of steel fiber content. The addition of 0.5% SFWT increases of compressive strength of HSFA concrete around 1.9%. The compressive strength of HSFA concrete continues to increase until the addition of 2% SFWT, with the value as shown in Table 4. The highest compressive strength was 49.23 MPa obtained in the 2% added SFWT specimen. This is around 9.99% increase compared to the compressive strength of HSFA concrete without SFWT.

Table 4. Test results for compressive strength.

Fly ash content (%)	Steel fiber content (%)	Tensile strength (MPa)	Increase of splitting tensile strength (%)
30	0	44.76	-
30	0.50	45.61	1.90
30	1.00	46.29	3.41
30	1.50	47.99	7.21
30	2.00	49.23	9.99

The replacement of cement by fly ash in high strength concrete with a content of 30% obtained a lower compressive strength than the planned compressive strength of 60 MPa due to the high volume of fly ash. This is because cement as the primary binder between aggregates is reduced and resulted in reduced concrete compressive strength. The more fly ash usage as a substitute of cement will decrease its compressive strength because the use of cement will be less and fly ash cannot be full as cement with binding function.

Although the compressive strength of the concrete does not reach the compressive strength of the target strength, the addition of SFWT to the concrete mix can increase the compressive strength. The increase of compressive strength due to the presence of the steel fiber which gives bonds to the concrete, the higher steel fiber, the higher the fiber bonds in HSFA concrete that increases in compressive strength of the HSFA concrete.

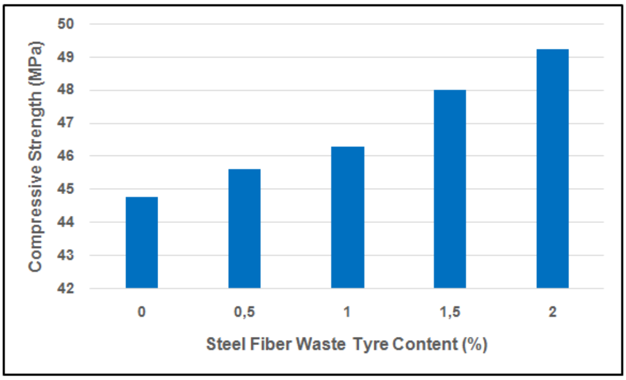


Fig. 6. Compressive strength vs. steel fiber waste tyre content.

4.2 Splitting tensile strength

Tensile strength test results of HSFA concrete with the addition of SFWT from 0-2.0% tested at day 28 can be seen in Table 5 and Fig. 7.

Table 5. Test result for splitting tensile strength.

Fly ash content (%)	Steel fiber content (%)	Tensile strength (MPa)	Increase of splitting tensile strength (%)
30	0	3.55	-
30	0.50	3.88	9.16
30	1.00	4.70	32.27
30	1.50	4.98	40.24
30	2.00	5.81	63.75

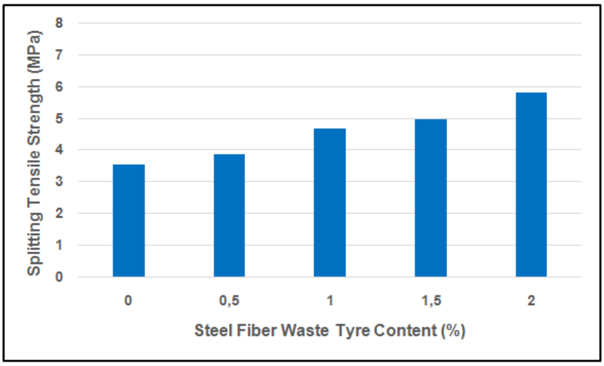


Fig. 7. Splitting tensile strength vs. steel fiber waste tyre content.

The result indicates that the splitting tensile strength of HSFA concrete increase with the increase of SFWT content in the concrete. The significant increase occurs at the rise of SFTW content from 0.5-1% and from 1-2%, which increases by around 23%. The highest tensile strength value was obtained at the addition of 2% SFWT that is 5.81 MPa, which is growing about 63.75% compared to HSFA concrete without the steel fiber.

The increase of the tensile strength might be due to the SFWT spread over all parts of the concrete inhibiting all the crack paths in the concrete. This causes the increase of concrete resistance to the crack. SFWT in the HSFA concrete is still able to cover the crack gaps when the concrete reaches the maximum load, and the ductile collapse occurs. That means that SFWT contributes to increasing the tensile strength of the concrete because the steel fiber can resist the cracks that occur in the HSFA concrete.

4.3 Flexural strength

Table 6. Test result for flexural strength.

Fly Ash content (%)	SFWT content (%)	Flexural strength (MPa)	Increase of flexural Strength (%)
30	0	6.68	-
30	0.50	6.84	2.36
30	1.00	7.34	9.76
30	1.50	7.49	12.12
30	2.00	7.90	18.18

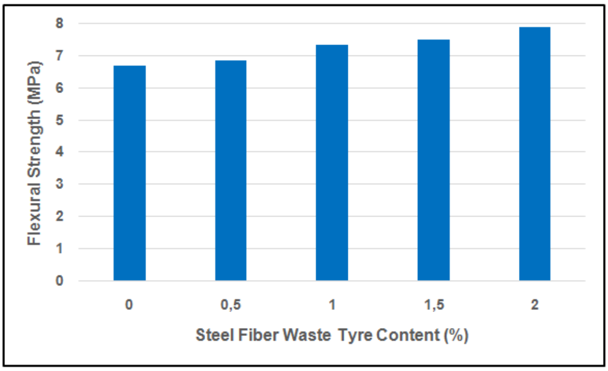


Fig. 8. Flexural strength vs. steel fiber waste tyre content.

The test results for flexural strength of the HSFA concrete with SFWT contents of 0%, 0.5%, 1.0%, 1.5%, and 2.0% can be seen in Table 6 and Fig. 8. As seen in the table and figure, the flexural strength of HSFA concrete increases slightly with the increase of SFWT content. The highest increase of flexural strength occurs at the addition of 2% SFWT that is 18.18% compared to the HSFA concrete without the steel fiber content. The maximum flexural strength was obtained in the addition of 2% SFWT, that is 7.90 MPa. During the flexural test of the beams, it is observed that the amount of cracks in HSFA concrete with SFWT content is less than those without SFWT and the steel fiber appeared at the location of the cracks of the HSFA concrete before failure. The increase in flexural strength can be attributed to the bonds and carrying capacity of steel fiber after the matrix has cracked [6].

This means that the more fiber in the concrete, the flexural strength of HSFA concrete will be stronger.

5 Conclusions

The addition of SFWT from 0.5% to 2% increases the compressive strength, tensile strength and flexural strength in high strength fly ash concrete. The presence of steel fiber in HSFA concrete can prevent the spreading of irregular small cracks in the concrete caused by the addition of load when the concrete is tested so that with the increase of steel fiber in the concrete the less likely the occurrence of cracks, increasing the concrete strength. The maximum compressive strength in HSFA concrete occurs in the addition of 2.0% fiber steel that is 49.23 MPa, with an increase in compressive strength of 9.99% compared with HSFA concrete without SFWT content. Addition of 2% SFWT in HSFA concrete reached the maximum tensile strength of 5.81 MPa, in which the increase of the tensile strength around 63.75% compared to 0% SFWT in the HSFA concrete. The maximum increase of flexural strength was found at 2% steel fiber content, which is around 18.18% increase compared to HSFA concrete without additional SFWT.

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